SIMULTANEOUS LASER PREIONIZATION OF DUAL SPARK COLUMNS IN A HIGH VOLTAGE SWITCH

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Abstract

The preliminary investigation of simultaneous laser triggering (λ=248 nm) of a spark gap (50 kV, 18 kA, 100 nsec) switch with two parallel preionized columns (separation 1.3 mm) is reported. Interferograms of the expanding arc channels are obtained with a laser interferometer having a time and spatial resolution of 5 ns and 10 μm, respectively. Comparison of the dual spark column voltage and current characteristics are made to those of a single channel spark column.

Introduction

During self-break of spark gaps, many breakdown filaments may be formed, resulting in the spark gap operating through many individual channels. The rate of expansion of the breakdown filaments may be sufficiently rapid, and the spacing of the breakdown filaments may be sufficiently small, that during the current pulse, the arc channels interact with one another. In many instances, it is desirable to have the spark gap operate through many channels. Multi-channel operation of rail gaps has long been recognized as a technique whereby the resistive loss and circuit inductance of the device can be reduced; however, the optimum spacing of the arcs in rail gaps tends to be large (many millimeters to a centimeter) as compared to the spark channel diameter (approximately 1 mm), suggesting that the arc channels can be too closely spaced. Therefore, the characterization of closely spaced, expanding arc channels is of interest for understanding the operation of both self-breaking spark gaps and multi-channel rail gaps.

The development of laser triggered spark gaps has provided the means whereby large electrical powers (megavolts at mega-amps) can be switched at voltages significantly less than the self-break value and with jitter less than a few nanoseconds [1]-[4]. The use of laser preionization triggering also produces a readily reproducible plasma channel between the spark gap electrodes that is amenable to study by laser interferometric techniques.

In this paper we report on preliminary studies of a laser triggered spark gap where two closely spaced parallel spark channels are preionized simultaneously. This preionization scheme results in a pair of nearly identical, reproducible expanding arc channels that can be studied both interferometrically and electrically. The spacing of the spark columns, 1.3 mm, is sufficiently small that they interact during a portion of the 100 ns current pulse. Details of the internal structure of each spark channel are obtained from the interferograms. A capacitive voltage divider was designed [5],[6] specifically for use in this particular spark gap in order to give an unambiguous measure of the voltage drop between the spark gap electrodes.

Experimental Setup

The experimental system, described in detail elsewhere [7] is shown in Figure 1. The apparatus consists of a 1.5 Ω, 100 ns waterline which is pulse charged in 1.8 μs by a two-stage Marx bank to a voltage of 40-60 kV. Attached to the waterline is a chamber which houses a laser triggered spark gap.

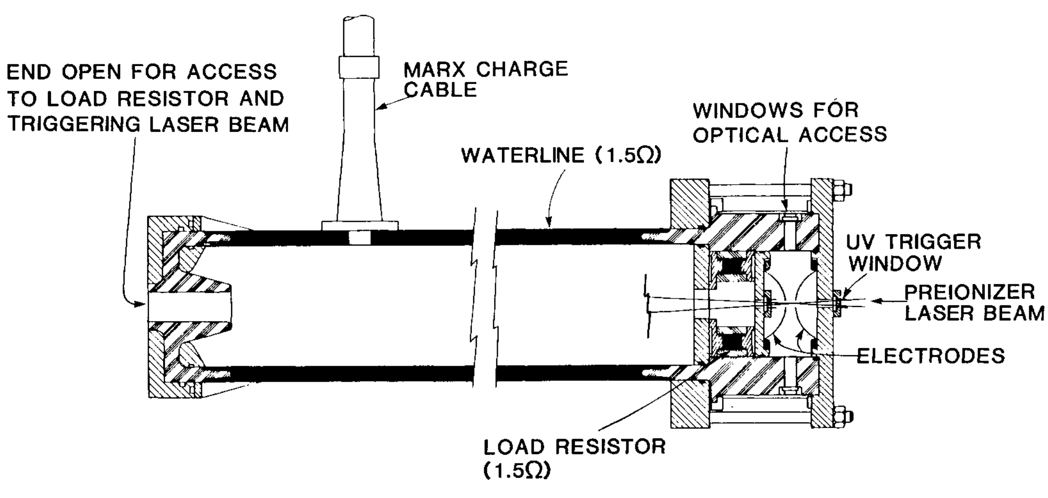

Figure 1. Schematic of experimental apparatus. The 1.5 Ω, 100 ns water pulse forming line is terminated by a liquid copper sulfate load resistor, and switched by the laser preionization triggered spark gap. The spark gap chamber is located in one leg of a Mach-Zender interferometer. The probe beam for the interferometer interrogates the arc perpendicular to the axis of symmetry. The probe laser enters and leaves the spark gap chamber through the optical access windows indicated.

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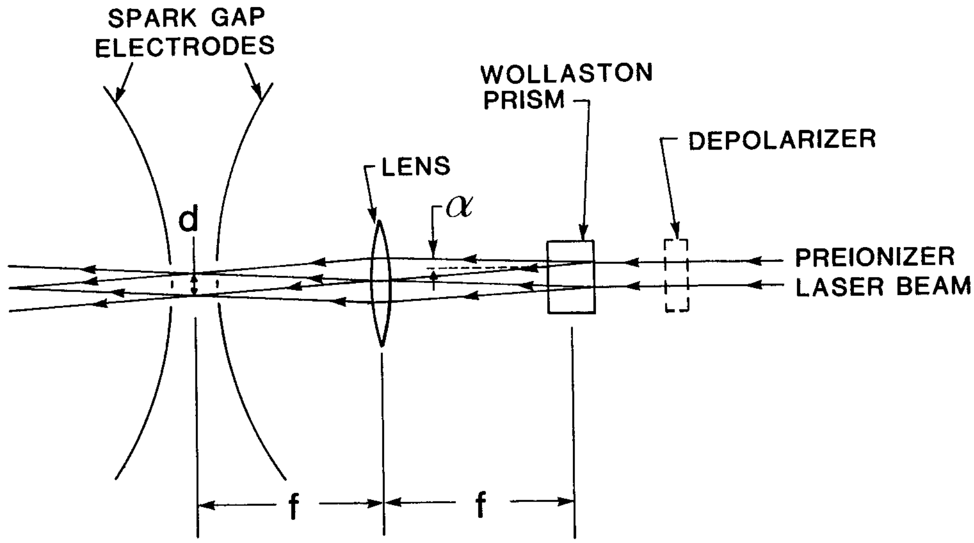

Figure 2. To achieve simultaneous triggering of two spark channels, the preionization laser passes through a Wollaston prism in which perpendicular polarizations are dispersed by an angle $\alpha = 0.4°$. A lens focuses the two individual beams, entering and leaving the inter-electrode gap coaxially through a pair of 1 mm holes in each electrode, separated by d = 1.3 mm. The minimum electrode spacing is 1.2 cm.

All the work described in Reference [7] deals with single channel laser triggered arcs. To produce two arcs simultaneously and in close proximity to each other, the optical delivery system for the preionization laser beam described in Reference [7] was modified as follows.

For the dual channel experiments, the spark gap consists of two hemispherical copper electrodes placed 1.2 cm apart, each having a pair of 1 mm-diameter holes separated by 1.3 mm at their centers. As depicted in Figure 2, the preionization laser beam is split into two separate beams by a Wollaston prism. The deflection angle, α, is ≈0.4° and the focal length of the focusing lens is 18 cm. To ensure equal laser energy in the two beams, a depolarizer is used before the Wollaston prism. The two beams enter the electrode gap through the pair of holes in the anode, are focused at a point midway between the electrodes, and pass through the opposite holes in the cathode without striking either of the electrodes.

The spark gap chamber is located within one leg of a laser interferometer, which is used to measure details of the spark channel internal structure with a spatial resolution of better than 10 μm and a time resolution of better than 5 nsec.

The ability to obtain simultaneous dual channels was found to be not only a function of the relative distribution of preionizer energy between the two beams, but also of the absolute amount of laser energy and the fraction of self-break voltage applied to the gap. In general, for a given amount of evenly distributed preionizer laser energy, the probability of simultaneity increases as the charging voltage approaches the self-break value. If the charging voltage is too low or, for a given charging voltage, the amount of laser energy is too small, the spark channel will randomly develop through one of the two channels, but not both. With sufficient laser power in each beam (≈200 μJ, 5 ns) and utilizing a depolarizer before the Wollaston prism (see Figure 2), reproducible, axisymmetric, and equal size dual spark channels are obtained. Temporal jitter is <5 ns, and spatial jitter is <10 μm.

Laser Interferometric Measurements of Dual Spark Columns

A typical sequence of channel formation in a laser triggered dual spark column appears in Figure 3. The gas mixture is $SF_6/N_2/He$:0.05/0.20/0.75, the gas pressure is 2 atm, and the charging voltage is ≈40 kV. The voltage corresponds to F_{SB} = 0.7, where F_{SB} is the fraction of the DC self-break voltage that the waterline is charged to at the time of laser triggering. The time the interferogram is taken with respect to the start of the current pulse is denoted by Δt.

The outermost fringe shifts are due to shock wave compression of the ambient gas. The downward fringe shift inside the columns and the abrupt fringe jump are caused by a rapid rise in the ionization of the gas, resulting in a core of high electron density. Reference [7] provides more details on the interpretation of the interferometric measurements for a single arc channel.

Electrical Characteristics of Spark Gaps With Dual Laser Triggered Channels

Current and voltage traces for dual spark columns were obtained and compared with those for single spark columns having otherwise identical conditions. A typical pair of I-V characteristics appear in Figure 4. One would expect that with the dual channel acting like two parallel resistors, the voltage drop would be significantly less than with a single channel. However, a qualitative inspection does not reveal a significant decrease in the voltage drop across the channel with dual channels as compared to a single channel.

There are two effects that account for the large voltage drop of the dual channels. First, the two spark columns are too close to each other, as compared to the dimension of the current return path, to significantly change the inductance of the gap. If

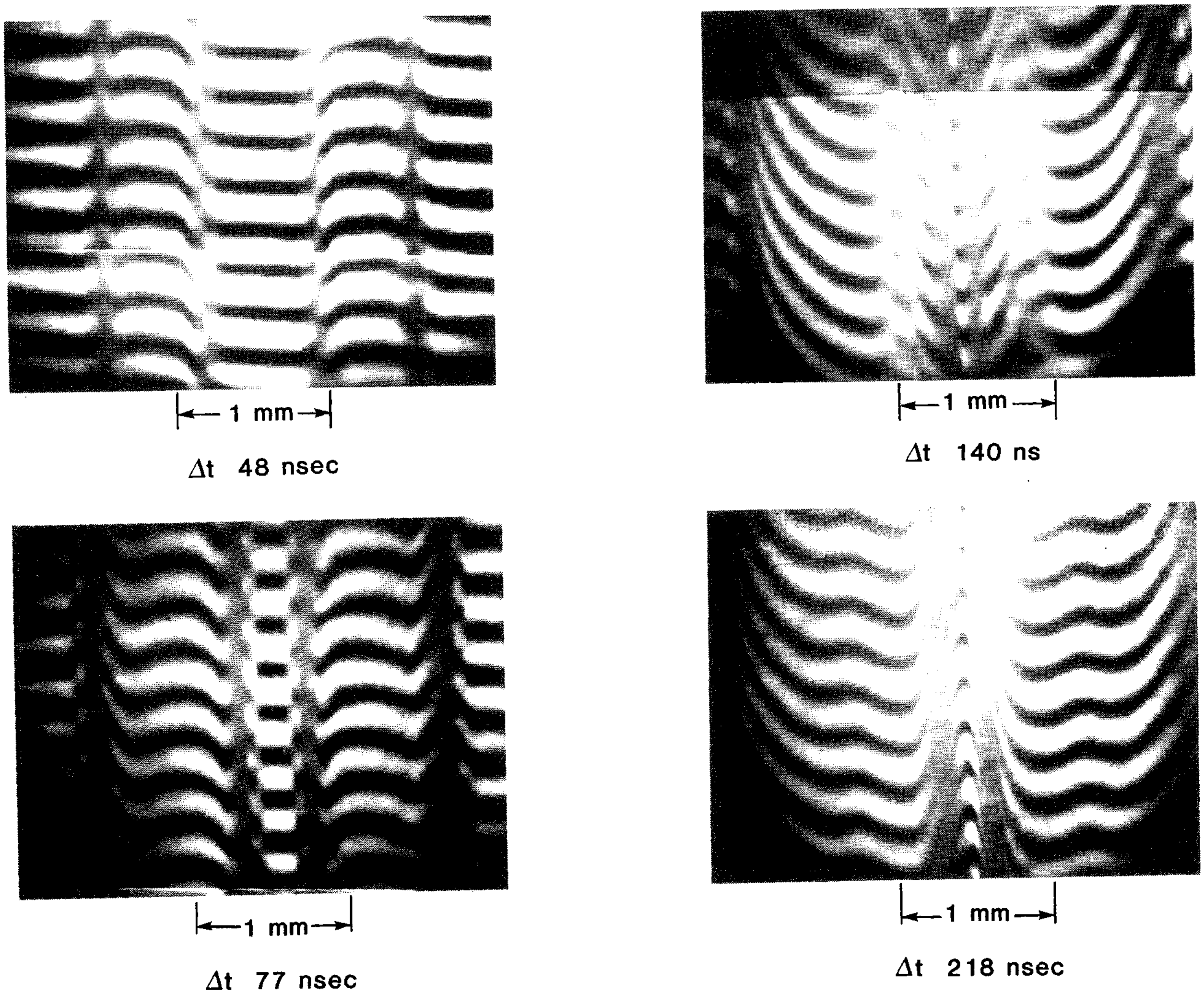

Figure 3. Laser interferograms for the expansion of dual channels in a $SF_6/N_2/He$:0.05/0.20/0.75 gas mixture. The initial pressure is 2 atm and the line voltage at triggering is 38 kV. The indicated time is the delay after laser triggering. The duration of the current pulse is ≈100 ns. The interferogram is centered between the spark gap electrodes, separated by 1.2 cm.

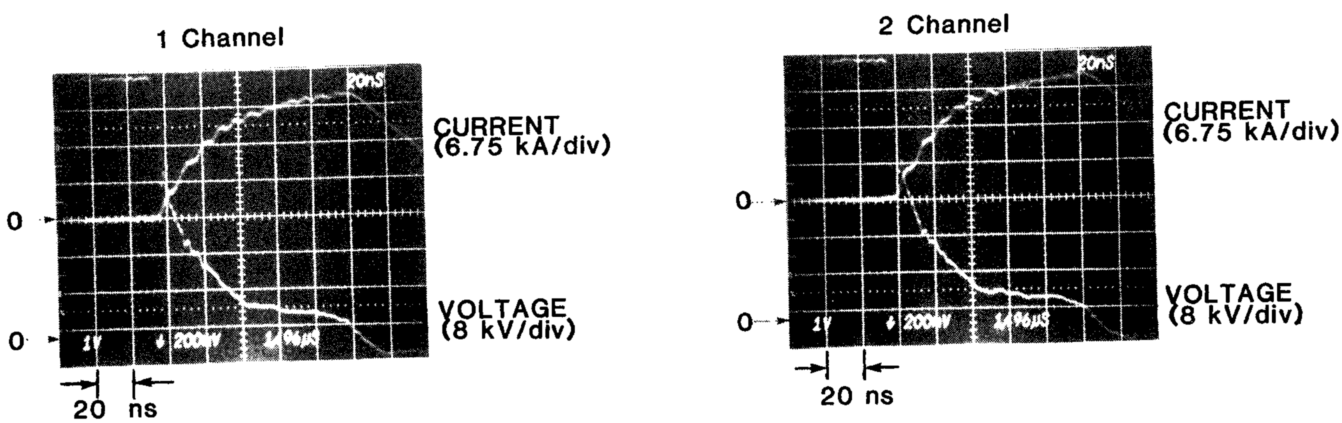

Figure 4. Current and voltage traces for the laser triggered spark gap shown in Figure 1 operating through a single channel (left figure) and two channels (right figure). The gas is 1.0 atm SF_6 and the line voltage at triggering is 56 kV.

the sparks were separated by a large distance, the inductance of the column could be reduced significantly. Therefore, for our conditions, the inductive voltage drop does not significantly change.

The second effect that accounts for the large voltage drop for the dual channels has to do with the specifics of the conductivity of the plasma columns. The degree of ionization of the arcs has exceeded the value required to reach Spitzer conductivity (1 to 10% ionization is sufficient). In this limit, the electrical conductivity of the plasma, σ, is nearly independent of the degree of ionization and is proportional to $T_e^{3/2}$, where T_e is the electron temperature [8]. The electron temperature is, in turn, a function of the rate of joule heating of the plasma, j^2/σ, where j is the current density. As a result of having two spark channels, the electron temperature decreases due to the sharing current (which reduces j) between the two columns. The decrease in electron temperature reduces the conductivity of the column and thereby increases the resistance of the spark column and (for constant current) increases the voltage drop.

Concluding Remarks

Laser preionization triggering is used to form a pair of parallel, symmetric, closely spaced (1.3 mm) spark channels; these channels were investigated using a pulsed laser interferometer and electrical probes. The rate of expansion of the arc channels is sufficiently fast that the channels collide during a portion of the current pulse (100 ns). The channels maintain their individual character and do not coalesce into a single channel due to the formation of a stagnation layer of gas compressed between the spark channels. Spark channels initiated without equal amounts of preionization laser energy do not grow symmetrically, and the stronger shock of the larger arc channel is able to penetrate into the weaker, smaller arc channel.

The voltage drop of a dual channel spark gap is only slightly smaller than that of a spark gap operating through a single channel. This results from a lower heating rate and, hence, smaller electrical conductivity, and a smaller rate of expansion of the individual columns in a dual channel spark gap as compared to a single channel.

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